NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
May 1945 as
Memorandum Report E5E21

RELATION BETWEEN FUEL ECONOMY AND CRANK ANGLE FOR THE MAXIMUM RATE OF PRESSURE RISE

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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

RELATION BETWEEN FUEL ECONOMY AND CRANK ANGLE FOR THE MAXIMUM RATE OF PRESSURE RISE

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SUMMARY

Investigations were conducted to determine whether the crank angle for maximum rate of pressure rise can be used to indicate maximum-economy spark advance. Maximum-economy spark advance was investigated in single-cylinder tests in which the crank angle for the maximum rate of pressure rise was measured. In a study of several engine variables a method was found of maintaining indicated specific fuel consumption at or near its minimum value by holding constant the crank angle for the maximum rate of pressure rise.

The results of the investigations indicate that maximum-economy spark advance is obtained by setting the spark advance so that the maximum rate of pressure rise occurs at about 3° A.T.C.

INTRODUCTION

At the request of the Army Air Forces, Air Technical Service Command, an investigation is being conducted at the NACA Cleveland laboratory to determine the best means of using high-antiknock hydrocarbons as components of aviation gasoline. As part of the program compression ratio and spark advance are being studied in an effort to improve fuel economy. The tests reported herein were conducted during the latter part of 1944 to determine the practicability of using the crank angle at the maximum rate of pressure rise to select the spark advance for maximum economy.

APPARATUS AND PROCEDURE

A full-scale air-cooled cylinder was mounted on a CUE setup. A magnetostriction pickup in the cylinder head gave a time-rate of pressure change diagram on an oscillograph. The crank angle at which the maximum rate of pressure rise (or any other cycle event as indicated on the oscillograph) took place was measured by electrical impulses that produced timing marks (vertical lines) on the oscillograph. Hereinafter θ_r will be used to denote the crank angle at which maximum rate of pressure rise occurs. The electrical impulses are generated by a pair of coils supported near the periphery of the flywheel. These coils have a magnetic circuit (soft iron cores and a small permanent magnet) with an air gap so arranged that special lugs projecting from the periphery of the 26-inch diameter flywheel pass close to the magnetic poles and induce a momentary voltage in the coils. The coils are on a carriage mounted on a segment of a circular track concentric with the flywheel. A pointer on the carriage indicates the crank angle.

Method of measuring θ_r. - The oscillograph was so adjusted that the peak in the diagram which indicated the maximum rate of pressure rise appeared near the center of the screen. A timing line was then made to coincide with this peak by moving the carriage supporting the timing coils. The pointer on the carriage then indicated θ_r. The same procedure was used to measure the crank angle of maximum pressure and other events in the pressure cycle.

Engine operating conditions. - The spark advance was varied in tests at different inlet-air pressures in order to study the relation of maximum-economy spark advance with the following engine variables: inlet-air pressure relative to exhaust pressure; engine speed; number of spark plugs firing; and compression ratio. The effect of fuel-air ratio on the spark advance for maximum economy was determined in constant-power tests.

The fuel used in all the tests was 28-R and the injection nozzle was located ahead of the vaporization tank. Engine conditions held constant are presented in table I.

RESULTS AND DISCUSSION

Spark-Advance Tests at Constant Inlet-Air Pressure

Test results are presented in figures 1 to 4 to show the effects of several engine variables (see table I) on the relation of maximum-economy spark advance, minimum indicated specific fuel consumption,

and θ_r. In general, minimum indicated specific fuel consumption occurred in all the tests when θ_r was from T.C. to 4° A.T.C. For each engine variable studied θ_r varied almost directly with spark advance.

Inlet pressure relative to exhaust pressure. - Figure 1 shows the results of tests in which the inlet-air pressure minus the exhaust pressure $(p_i - p_e)$ was varied. The maximum spark advance studied in the two tests with atmospheric exhaust pressure was limited by knock.

When the inlet-air pressure relative to the exhaust pressure was varied, the loss of unburned charge during valve overlap and the presence of residual gases affected the indicated specific fuel consumption. For any value of θ_r the differences in indicated specific fuel consumption are attributed primarily to loss of unburned charge during valve overlap. At constant spark advance, however, comparisons of indicated specific fuel consumption are made difficult by the fact that residual gases retard combustion.

Engine speed. - When the engine speed was increased from 2100 to 2500 rpm (cf. figs. 1 and 2), the relation of indicated specific fuel consumption and θ_r was not changed. Unpublished tests at low engine speeds, 1400 and 1800 rpm, further substantiate this fact.

One spark-plug operation. - The engine performance with only the front spark plug firing is presented in figure 3. For comparison with engine performance when both spark plugs were firing, data from figure 1 are included. Although the engine performance was slightly different with one and two spark-plug operation, the relation of the minimum indicated specific fuel consumption and θ_r was the same.

Operation at a compression ratio of 10. - In the tests run at a compression ratio of 10, an exhaust pressure of 10 inches of mercury absolute was used in order to operate below the knock limit. The test results presented in figure 4 at a high and a low fuel-air ratio show that the high compression ratio did not affect the relation of the minimum indicated specific fuel consumption and θ_r. That the fuel-air ratio also had no effect on the relation should be noted.

Comparison of crank angle for maximum pressure and θ_r. - The relation of the crank angle for maximum pressure and θ_r for the foregoing tests of engine variables is presented in figure 5. The data show that the maximum cylinder pressure occurred 10.5° ±3.5° after θ_r. Comparison of test results presented in figures 1 to 5 indicates that minimum indicated specific fuel consumption correlates better with θ_r than with the crank angle for maximum pressure. In

each of the tests the indicated specific fuel consumption at θ_r of 3° A.T.C. was within 0.3 percent of its minimum value. Running at θ_r of 3° A.T.C. is therefore a convenient method of operating at maximum-economy spark advance.

Fuel-Air-Ratio Tests with Constant θ_r of 3° A.T.C.

The results of variable fuel-air-ratio tests at constant power with θ_r held at 3° A.T.C. are presented in figure 6. The spark advance required to hold θ_r at 3° A.T.C., for exhaust pressures of both atmospheric and 15 inches of mercury absolute, did not differ by more than 1° at any fuel-air ratio. The higher indicated specific fuel consumption with the low exhaust pressure was attributed to an increase in the amount of the charge lost during valve overlap.

SUMMARY OF RESULTS

The following results were obtained in single-cylinder tests conducted to study the relation of maximum-economy spark advance and crank angle for the maximum rate of pressure rise:

1. Holding the crank angle for the maximum rate of pressure rise constant at 3° A.T.C. proved to be a successful means of operating at spark advance for maximum economy. Indicated specific fuel consumption was within 0.3 percent of its minimum value, when the maximum rate of pressure rise occurred at 3° A.T.C.

2. Increasing the inlet-air pressure relative to the exhaust pressure caused an increase in indicated specific fuel consumption due to the increased loss of unburned charge during valve overlap.

3. In all the tests the maximum cylinder pressure occurred 10.5° ±3.5° after the maximum rate of pressure rise. Minimum indicated specific fuel consumption correlated better with the crank angle of maximum rate of pressure rise than with the crank angle for maximum pressure.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, May 21, 1945.

TABLE I - ENGINE CONDITIONS USED IN SPARK-ADVANCE AND FUEL-AIR-RATIO TESTS

Engine condition	Engine variable investigated							
	Inlet pressure - exhaust pressure $p_i - p_e$ (in. Hg)				Engine speed, 2500 rpm	Operation with front spark plug only	Compression ratio, 10	Fuel-air ratio and spark advance[a]
	20	5.8	5	-9.5				
Engine speed, rpm	2100	2100	2100	2100	2500	2100	2100	2100
Fuel-air ratio	0.065	0.065	0.065	0.065	0.065	0.065	0.065,0.099	Varied
Inlet-air pressure, in. Hg absolute	35	35	20	20	35	35	20	Varied
Exhaust pressure, in. Hg absolute	15	29.2	15	29.5	29.2	29.4	10.1	15.1,29.6
Inlet-air temperature, °F	150	150	150	150	150	150	150	150
Cylinder temperature at the rear spark plug, °F	450	450	450	450	450	Varied 396-438	450	Varied 356-464
Cooling-air pressure drop, in. water	Varied	Varied	Varied	Varied	Varied	4	Varied	3.3,4
Compression ratio	6.9	6.9	6.9	6.9	6.9	6.9	10	6.9

[a]Spark advance was varied to maintain crank angle for maximum rate of pressure rise at 3° A.T.C.

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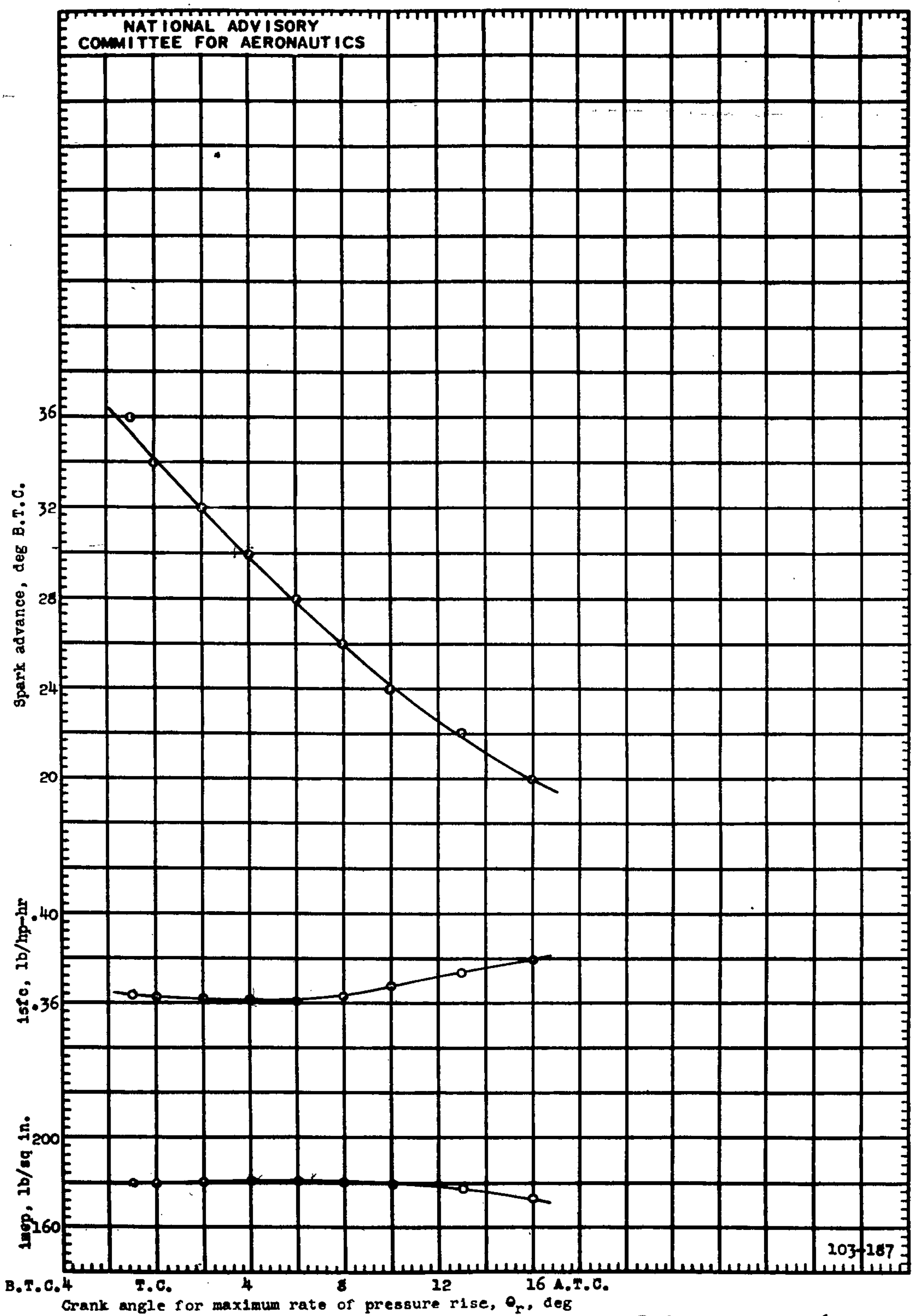

Figure 2. - Engine performance at an engine speed of 2500 rpm. Fuel-air ratio, 0.065; inlet-air pressure, 35 inches of mercury absolute; exhaust pressure, 29.2 inches of mercury absolute; inlet-air temperature, 150° F; cylinder-head temperature, 450° F; compression ratio, 6.9; fuel, 28-R.

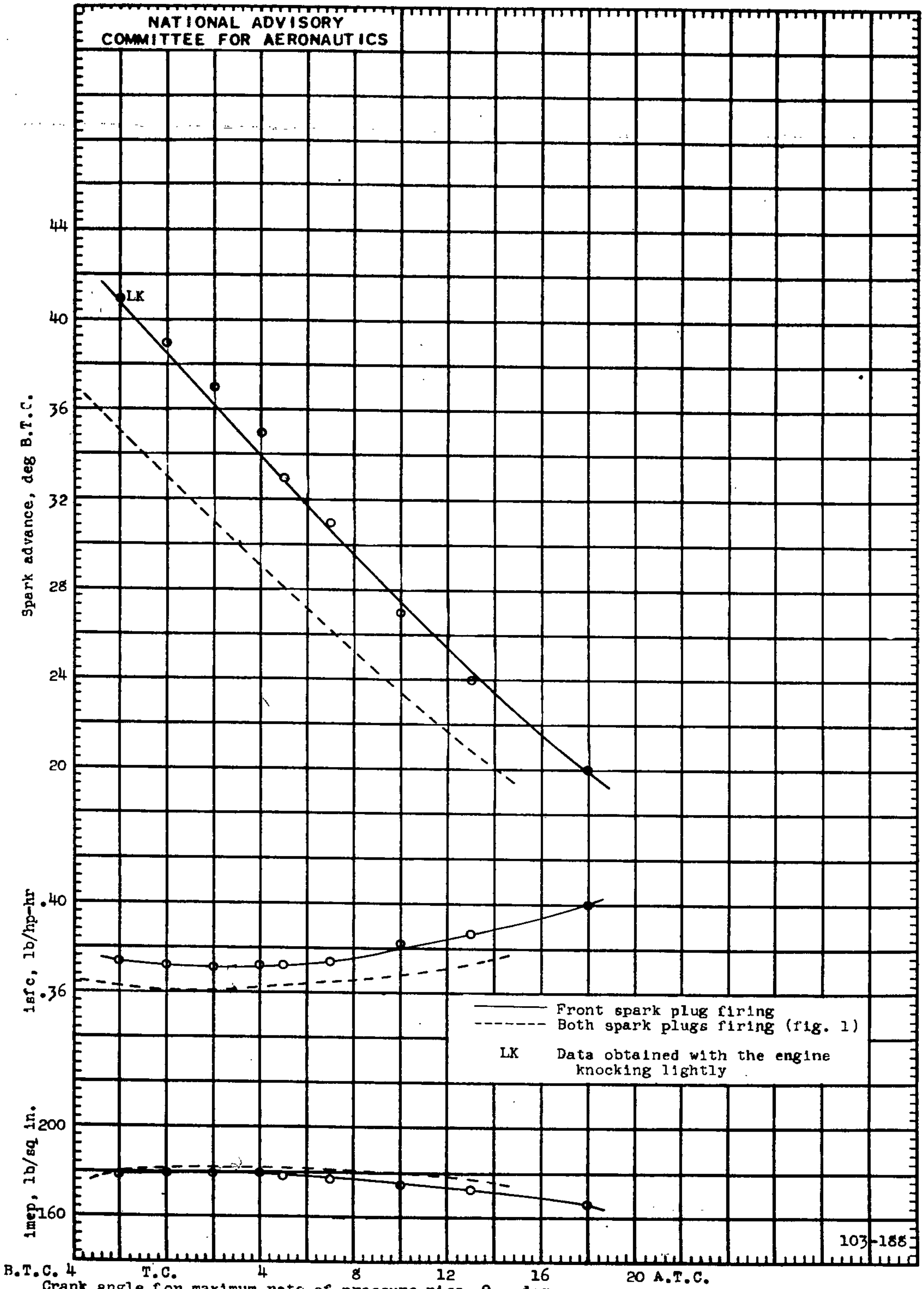

Figure 3. - Effect on engine performance of firing only the front spark plug compared with performance with both spark plugs firing (fig. 1). Engine speed, 2100 rpm; fuel-air ratio, 0.065; inlet-air pressure, 35 inches of mercury absolute; exhaust pressure, 29.4 inches of mercury absolute; inlet-air temperature, 150° F; cooling-air pressure drop, 4 inches of water; compression ratio, 6.9; fuel, 28-R.

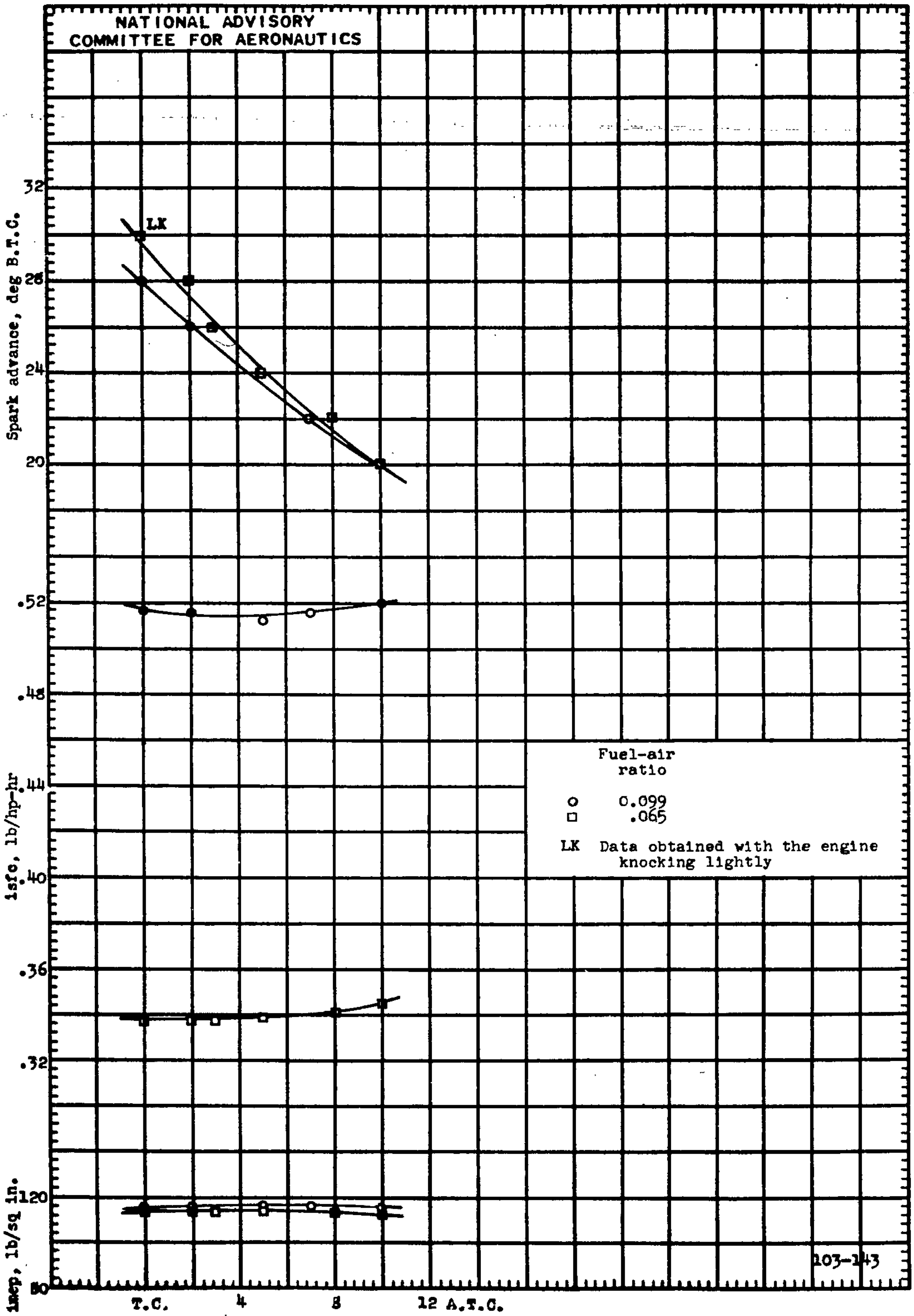

Figure 4. - Engine performance at high compression ratio (10) with high and low fuel-air ratios. Engine speed, 2100 rpm; inlet-air pressure, 20 inches of mercury absolute; exhaust pressure, 10.1 inches of mercury absolute; inlet-air temperature, 150° F; cylinder-head temperature, 450° F; fuel, 28-R.

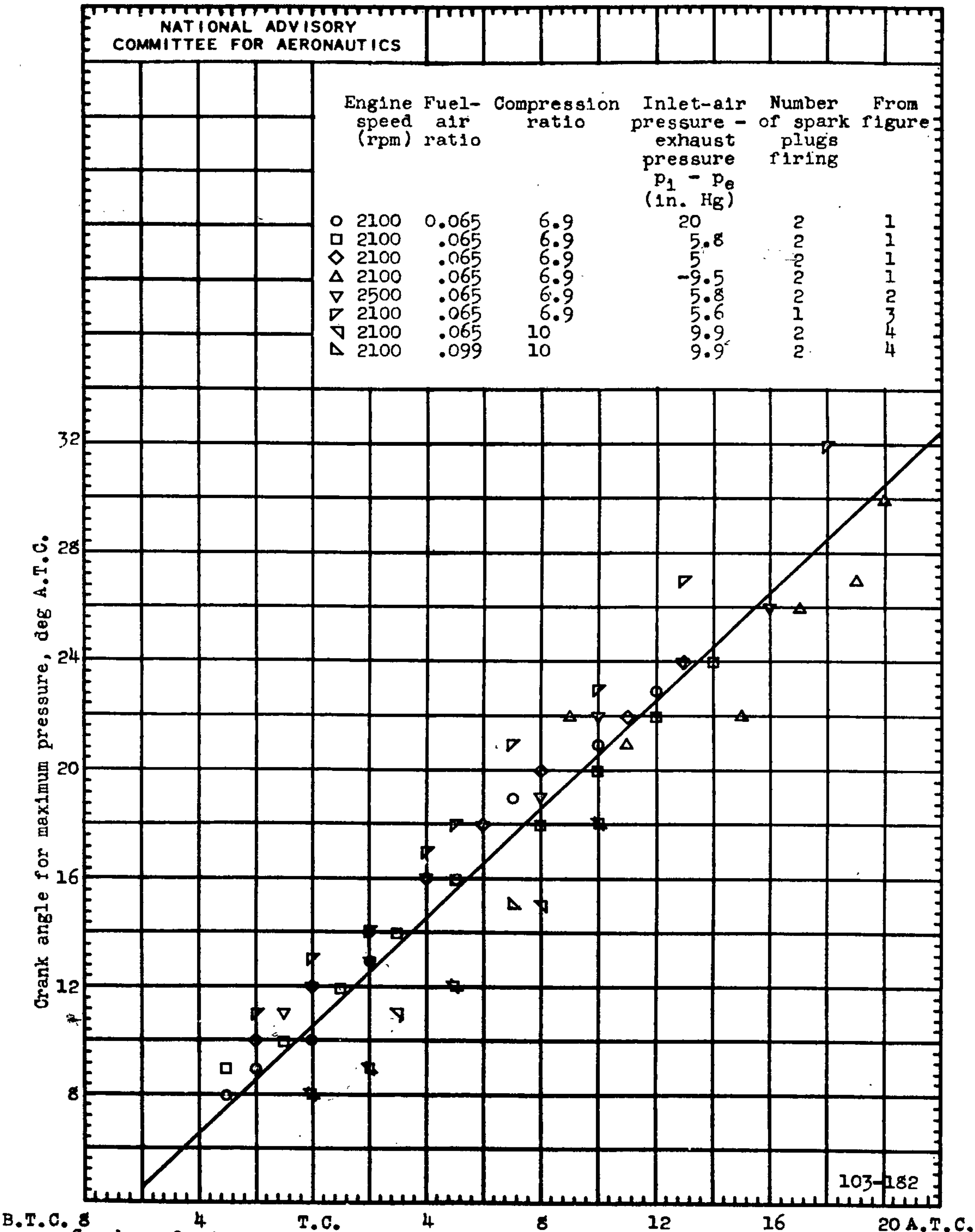

Figure 5. - Comparison of crank angle for maximum pressure and θ_r in tests at constant inlet-air pressure and constant fuel-air ratio.

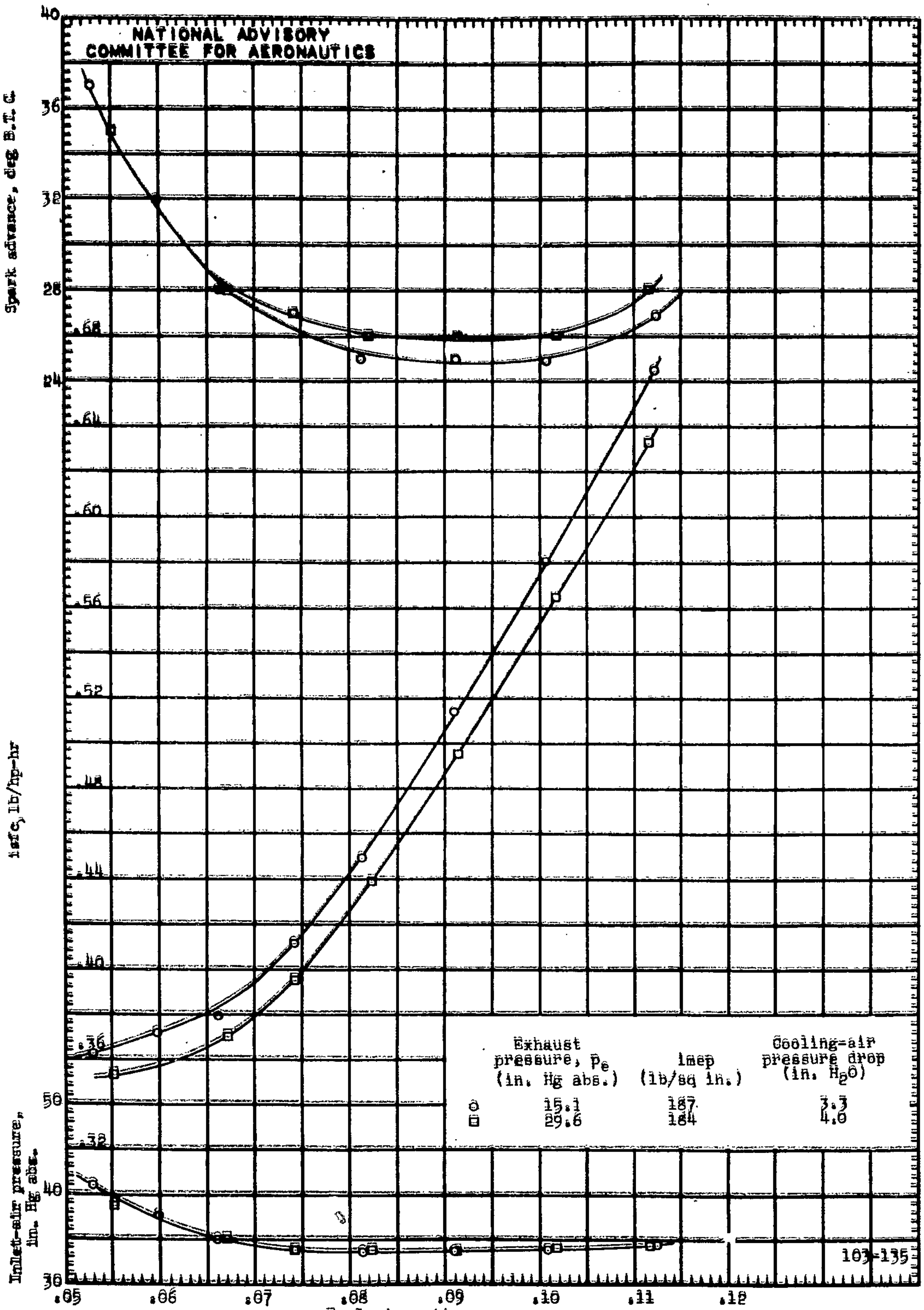

Figure 6. - Effect of fuel-air ratio on engine performance with constant (3° A.T.C.) crank angle for the maximum rate of pressure rise. Engine speed, 2100 rpm; inlet-air temperature, 150° F; compression ratio, 6.9; fuel, 28-R.

1 2 3 4 5
6 7 8 9 10
11 12 13